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DEVELOPMENT OF AN IMPROVED SMOKE INSPECTION GUIDE

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Cincinnati, Ohio

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DEVELOPMENT OF AN IMPROVED SMOKE INSPECTION GUIDE

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this document may be better
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Present methods of black smoke inspection generally involve visual observation of the degree of blackness of the smoke as it leaves the source, and comparison to a shade of standard blackness. Although all methods of visual black smoke density observation share many drawbacks [1], these methods are, for economic reasons, the only ones open to most municipal enforcement officials. Standards used by air pollution control agencies are usually of one of two basic types: (1) Reflectance type, which includes the Ringelmann Chart [2,3] and smaller card sized versions [4] reproduced to give equivalent shades of blackness; (2) Transmittance type [5,6], including those comparators employing film and other translucent reference slides which are viewed against the sky, generally through a collimating system.

REFLECTANCE AND TRANSMITTANCE TYPE STANDARDS

The standards of both categories have disadvantages as well as advantages. The major drawback of the reflectance type of smoke inspection guide [1,6] is that a smoke plume, whose shade of blackness is due primarily to transmitted light, is visually compared to an opaque reference giving only reflected shades of blackness. Variations of the intensity and color of the incident light will vary the relative appearance of the smoke and reference standard. Hence a plume of constant density may under different illumination give quite different Ringelmann values. The principal advantage of the reflectance type is simplicity and low cost.

Transmittance type smoke inspection guides, while overcoming the major drawback of the reflectance type, are at present expensive. The use of translucent reference shades of blackness enables a comparison of the smoke and transmittance guide to be made, based on the same optical principle of operation.

The objective of the present study is to evaluate the performance of both guide types and based on this evaluation to develop a smoke inspection standard embodying the following characteristics: 1) The new smoke guide must be simple, inexpensive, and suitable for general field use by smoke inspectors; 2) the reference guide should correlate with the black smoke plume under field conditions; 3) to be useful to enforcement agencies without requiring extensive revision of legislation, the new guide must be capable of correlating with the nominal standards currently in use.

TEST APPARATUS AND PROCEDURES

To establish a correlation of the comparator guides to the black smoke under an extreme range of field lighting conditions, a source of smoke was needed which could be maintained constant over extended periods of time. Due to the fluctuating nature of combustion smoke, a simulated smoke standard was developed which exhibited the same optical behavior as black smoke under field lighting conditions. It consisted of an aqueous suspension of colloidal carbon contained in a clear Lucite cell three inches thick and twenty-four inches on a side (Fig. 1). The use of such a controlled

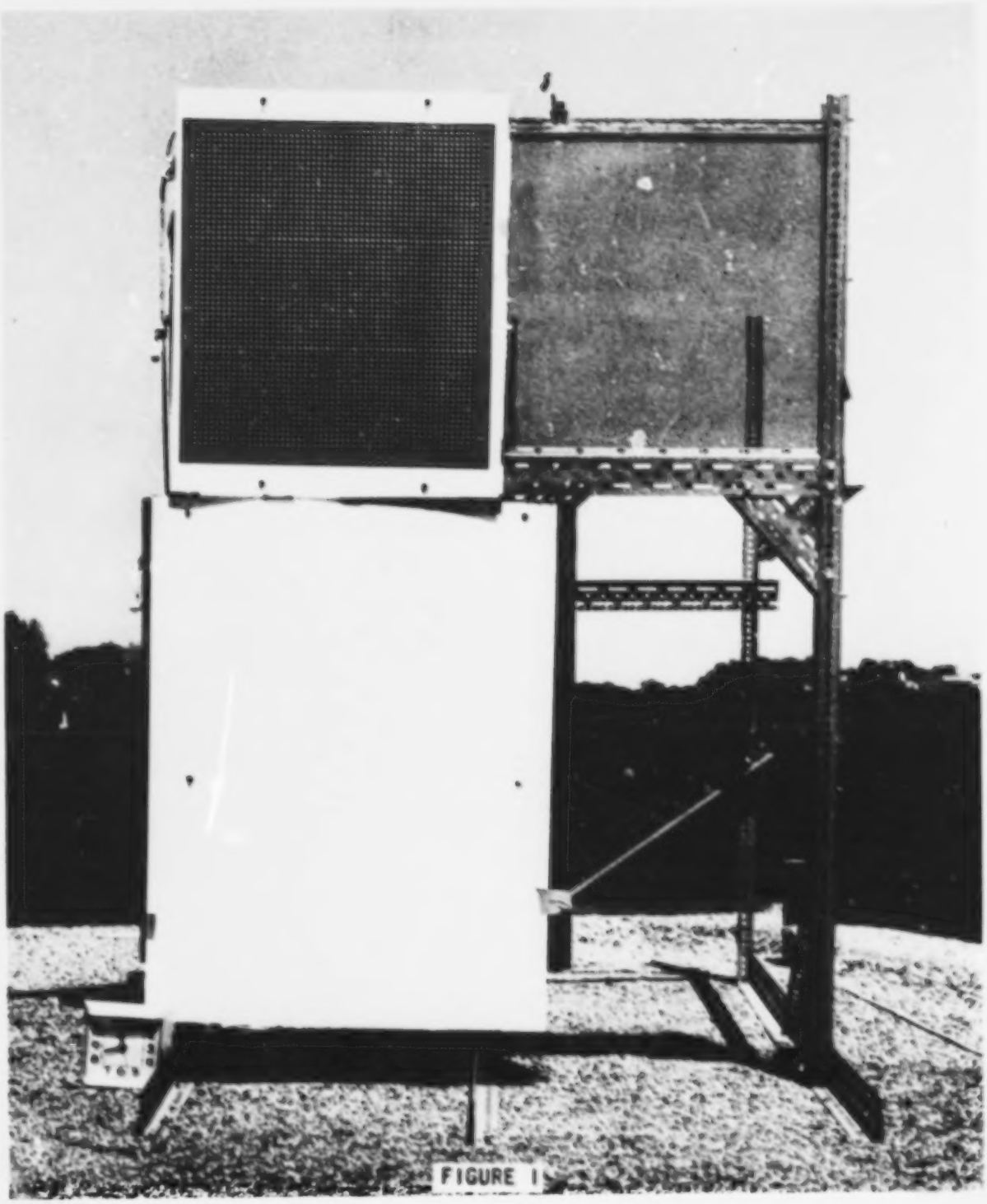


FIGURE 1

"smoke" removed one of the major variables encountered in the field and permitted a direct evaluation of the guides for changes in lighting conditions.

The selection of the guides used in the study was based on their availability and ease of manipulation. The U. S. Bureau of Mines Ringelmann Chart was chosen as representative of the reflectance type guide, and exposed photographic film as representative of the transmittance type guide.

PRELIMINARY INVESTIGATION

In practice the inspector's evaluation of a smoke involves a subjective judgment. The influence of psychological factors such as learning, light contrast, and environmental interferences makes necessary a statistical treatment of the data for a proper test evaluation. A preliminary statistical study was made to evaluate the performance of a film type guide as compared to a Ringelmann type chart. Tests were performed in the laboratory using simulated smoke, controlled lighting and background conditions, and a panel of four observers selected from a group of six subjects tested. The results demonstrated better correlation between the smoke and film values and greater stability of the film readings under these conditions.

For a performance evaluation of the guides under field conditions, the present study was conducted under atmospheric illumination. To eliminate the subjective elements inherent in the preliminary study, objective measurements were made using photometric instrumentation.

APPARATUS AND PROCEDURES

The instrumentation used in this investigation is shown in Fig. 2. A photometer (Photovolt, Model 520-M photomultiplier) selected for its high sensitivity was used in taking all light intensity readings. This instrument will measure luminous flux over four decimal ranges extending from a minimum of 5×10^{-8} to 5×10^{-3} foot candles. To determine the amount of light transmitted by the smoke or film strip or reflected by the Ringelmann Chart, it was necessary to limit the light reaching the photometer to that emanating from the specific areas under observation. For this purpose, a collimating tube was constructed which permitted a maximum scanning angle of 1.6°. A sighting tube mounted on the barrel of the collimator permitted accurate selection of the areas to be scanned.

In the experiments the instrument was set facing approximately north, with the collimator sighted just above the horizon. The smoke standard and Ringelmann Chart were placed 50' in front of the instrument at a height determined by its line of sight (Fig. 3).

At 50' the collimator subtends a field of view 17" in diameter. To provide this necessary area, the Ringelmann Charts as well as the standard smoke cell were made a minimum of 24" on a side. The Ringelmann Charts were prepared by cutting and mounting twelve of the 6" by 9" published charts on large pieces of white poster board. The smoke cell and chart to be studied were mounted on a frame which was set normal to the instrument line of sight.

FIGURE 2

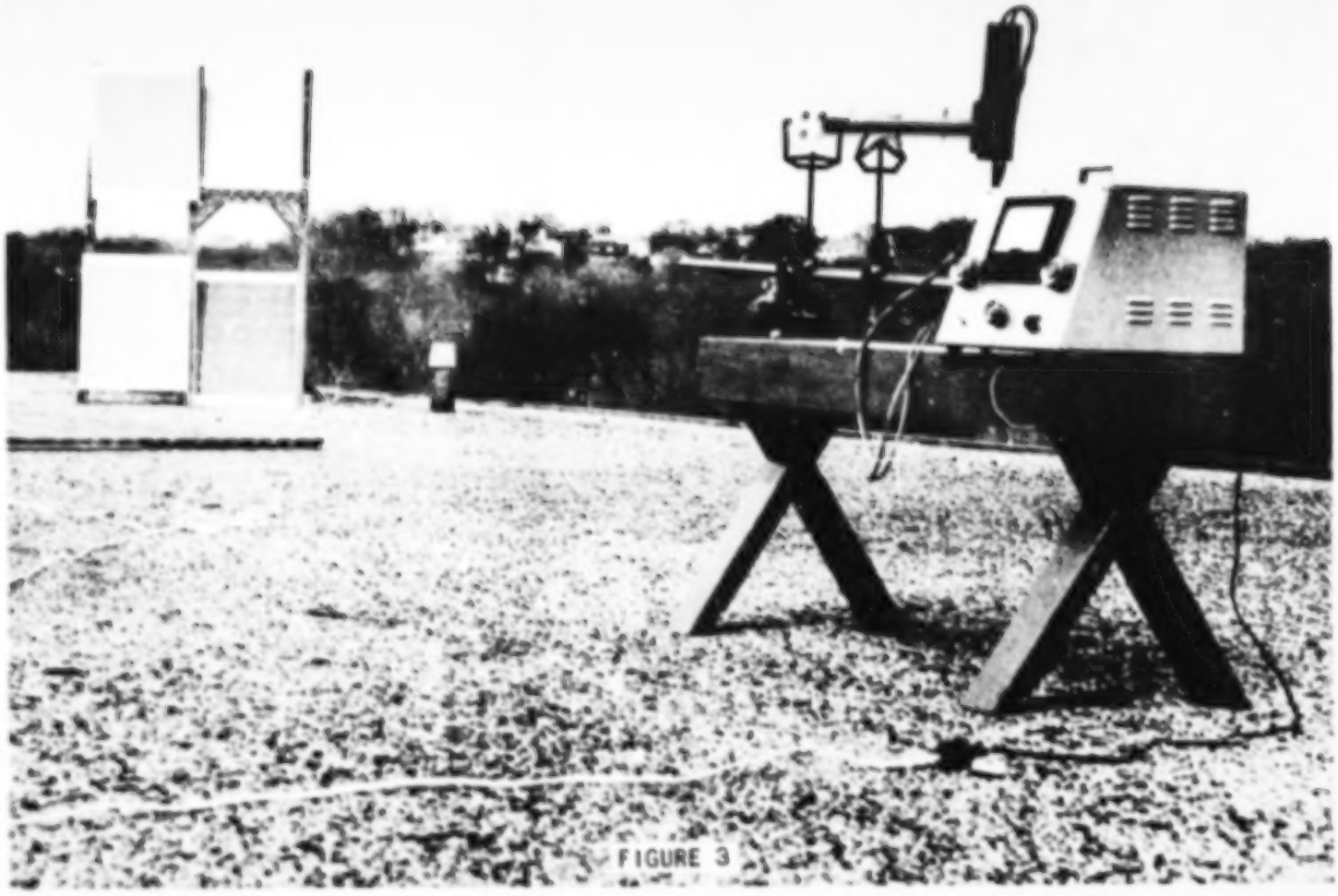


FIGURE 3

The film guide tested consisted of small film strips of the same neutral coloration as the standard smoke, and for testing purposes was mounted 1" from the end of the collimator. This distance was 19" from the photomultiplier and corresponds to the approximate distance the chart would normally be held from the eye. Preliminary tests proved that the observed transmission of the film remained essentially constant for the instrument independent of the distance.

In conducting the performance tests, light intensity readings were taken at one-half hour intervals between 11:00 A.M. and 5:00 P.M. To obtain a complete set of readings, light intensity was measured as received from the film, the smoke, the Ringelmann Chart, and the adjacent sky background. During tests conducted in clear weather, a transit set along the projected axis of the collimator was used to determine the position of the sun at the time of each set of readings.

SMOKE STANDARD VERIFICATION

Atmospheric illumination is both a complex and variable system, consisting of diffuse sky light and direct sunlight. The relationship of this complex system to the light properties of a black smoke plume will depend on three conditions: first, the degree of overcast or haze as it affects the intensity and constancy of diffuse light; second, the intensity and orientation of the incident sunlight; and third, the variance of intensity ratios of diffuse to direct light.

An evaluation of the relationship of the physical to the optical characteristics of the black smoke plume under atmospheric illumination

indicates: first, the suspensoids comprising the black plume, are predominantly solid carbon particles which are opaque and have extremely low reflectance; second, the particle size spectra lie above the size range necessary to produce significant light interference phenomena. Consequently, under conditions of atmospheric illumination, the plume can be expected to exhibit the optical properties of low light scattering and high light absorption.

In order that the performance of the two guide types be studied under conditions which are representative of actual field conditions, it is necessary that the simulated smoke standard exhibit the same optical characteristics as a plume itself. The suspensoid used in the smoke standard was colloidal carbon, which is opaque and has low reflectance. The physical difference between the suspensoids in a plume and the colloids which may affect their optical characteristics is the comparative particle size spectrum of each. Absorption measurements of the smoke standard employing a Beckman spectrophotometer Model B gave essentially equal values over the range of visible light from 4500 to 6500 Angstroms, thus indicating no significant light interference effects. As a result it was concluded that the particle size spectrum was not critical and the standard possessed optical properties equivalent to those of black smoke.

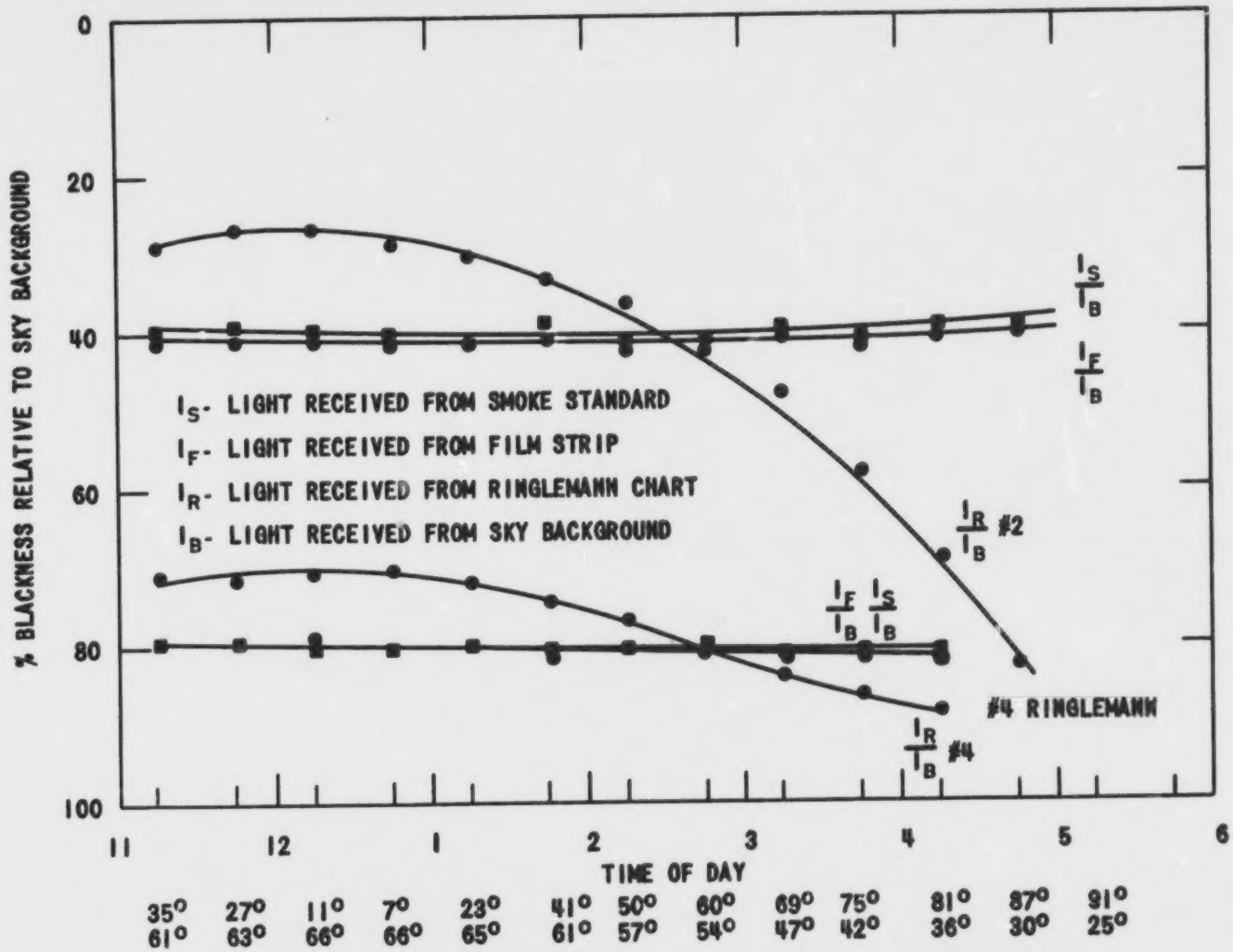
EXPERIMENTAL RESULTS

Because of the complexity and variability of the atmospheric illumination system, an empirical approach was used in studying the reflection and transmission guides chosen for evaluation. Comparisons of the guides

were made for two degrees of blackness, the first at an equivalent Ringelmann Number 2 and the second at an equivalent Ringelmann Number 4. These levels were chosen to cover a sufficient range in degree of blackness to arrive at a practical evaluation of the behavior trends over the entire range.

Two practical methods of application of smoke inspection guides are possible under field conditions: 1) an indirect comparison of blackness of the guide relative to the sky background to that of the smoke plume relative to the sky background; 2) a direct comparison of the blackness of the guide to that of the smoke plume. Therefore, evaluation of the experimental data is presented in terms of both methods. Since all evaluations are on a comparative basis, essentially simultaneous measurements were made of the light received from each type of guide under identical atmospheric illumination.

The first phase of the study covers the evaluations made from data obtained during clear (no clouds, no haze) sunny days representing periods of ideal atmospheric illumination in which the intensities of direct and diffuse light varied uniformly. Results, according to the first method, relating percent blackness (defined as the light intensity received from the smoke standard or guides divided by the light intensity received from the sky background) of the inspection guide and the smoke standard relative to the sky background (Fig. 4) show three significant facts: 1) the percent blackness of the smoke standard is independent of the sun's orientation and of the variation in its illumination intensity; 2) the percent blackness of the film strip correlates with that of the smoke standard and is,


0
20
40
60
80
100
% BLACKNESS RELATIVE TO SKY BACKGROUND
I_S- LIGHT RECEIVED FROM SMOKE STANDARD
I_F- LIGHT RECEIVED FROM FILM STRIP
I_R- LIGHT RECEIVED FROM RINGLEMANN CHART
I_B- LIGHT RECEIVED FROM SKY BACKGROUND
$\frac{I_S}{I_B}$
$\frac{I_F}{I_B}$
$\frac{I_R}{I_B}$ #2
$\frac{I_F}{I_B}$ $\frac{I_S}{I_B}$
#4 RINGLEMANN
$\frac{I_R}{I_B}$ #4
11 12 1 2 3 4 5 6
TIME OF DAY
35° 27° 11° 7° 23° 41° 50° 60° 69° 75° 81° 87° 91°
61° 63° 66° 66° 65° 61° 57° 54° 47° 42° 36° 30° 25°
SUN'S POSITION, HORIZONTAL DEVIATION AND VERTICAL ELEVATION

BLACKNESS OF SMOKE, FILM, AND RINGLEMANN CHART RELATIVE TO SKY BACKGROUND

CLEAR SUNNY SKY

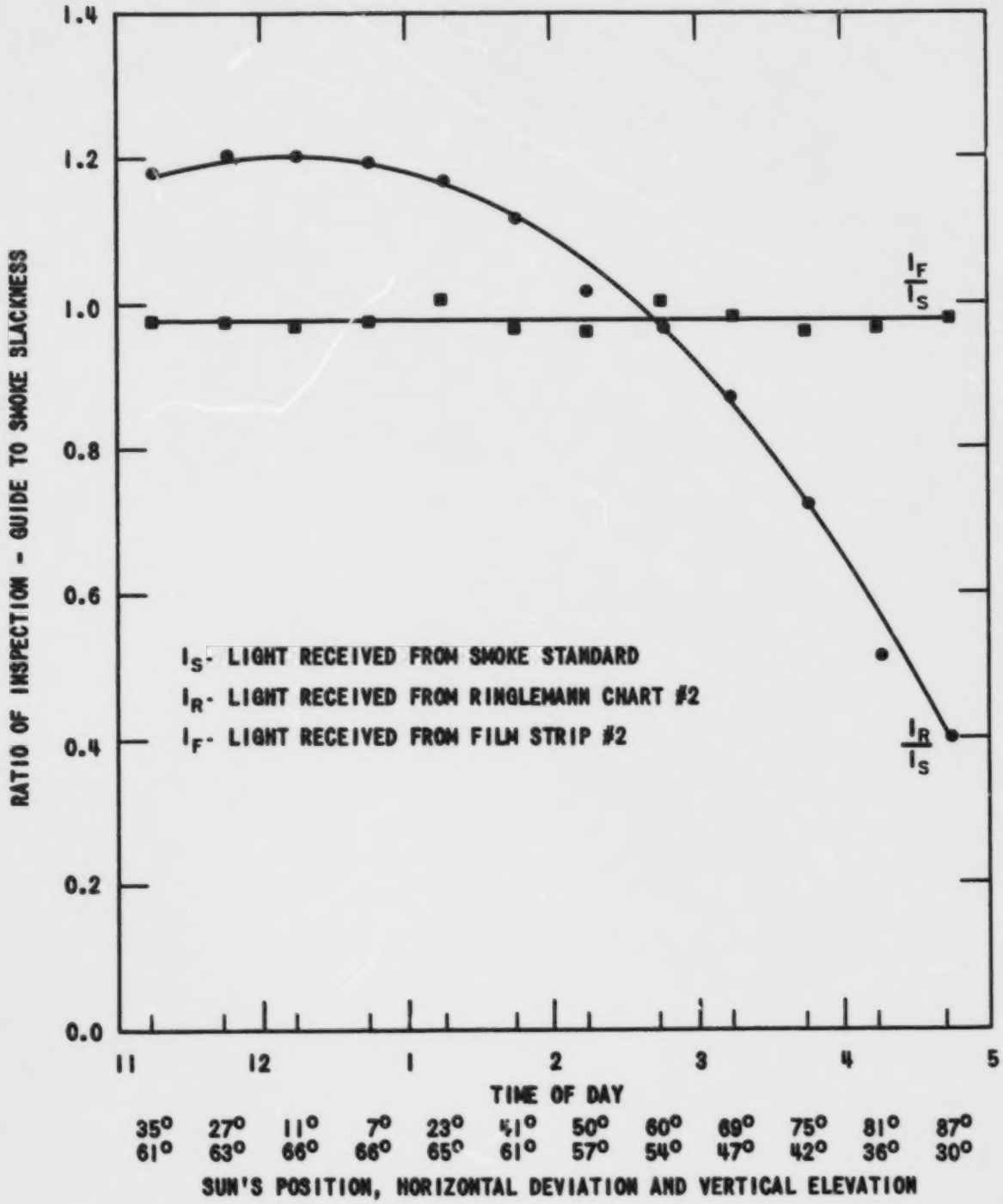
4/30/57 AND 5/1/57

FIGURE 4

furthermore, independent of the variations in the illumination system; 3) the percent blackness of the Ringelmann Chart, however, is dependent on the orientation of the sun and on the variation of its illumination intensity. Although the variation in the percent blackness of the Ringelmann Chart is uniform, it is not predictable under field conditions.

When the results are evaluated on the basis of a direct comparison, they are expressed as a ratio of absolute values of light intensity received from the guide to corresponding values from the smoke standard (Figs. 5,6). The results again verify the excellent correlation of the degree of blackness of the film strip with that of the smoke standard through varying light conditions as indicated by a maximum deviation of 4.2%. Since the degree of blackness of the guides relative to that of the smoke standard is shown as a ratio, it can be expressed as a percentage deviation. On this basis there is indicated a trend which shows that, under conditions of ideal atmospheric illuminations, the percent deviation of the Ringelmann Chart increases with the degree of blackness of the smoke standard.

A further evaluation of the performance of the guides was made based on an experiment in which the horizontal component of the angle of incidence of the direct sunlight to the guides was held constant at zero degrees, and the vertical component of the angle of incidence was allowed to vary as the sun approached the horizon (Fig. 7). The conclusions previously reached regarding the constancy of the film guide and the variability of the Ringelmann Chart continued to hold under these special

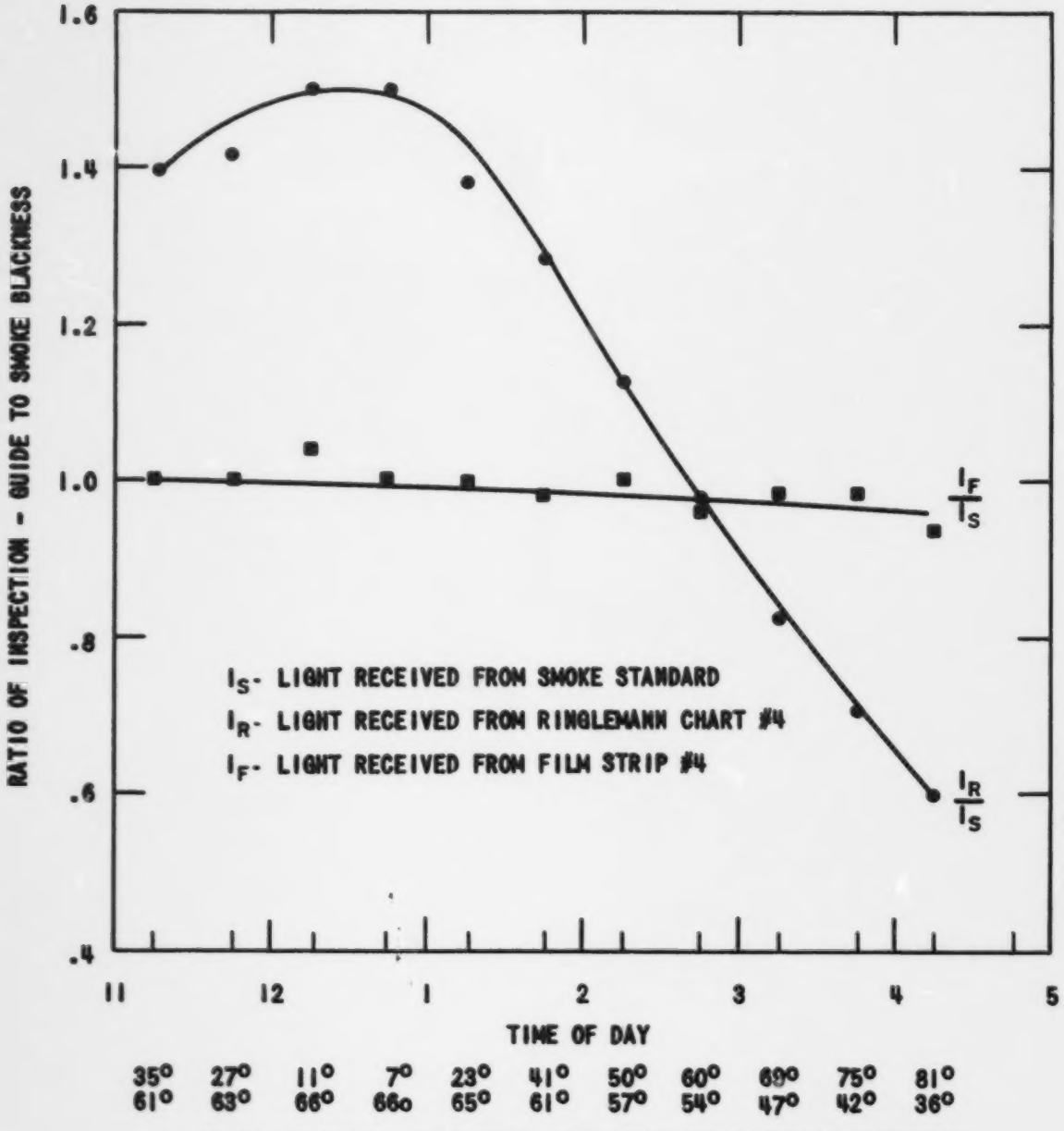


RATIO OF INSPECTION GUIDE TO SMOKE BLACKNESS

CLEAR SUNNY SKY

4/30/57

FIGURE 5

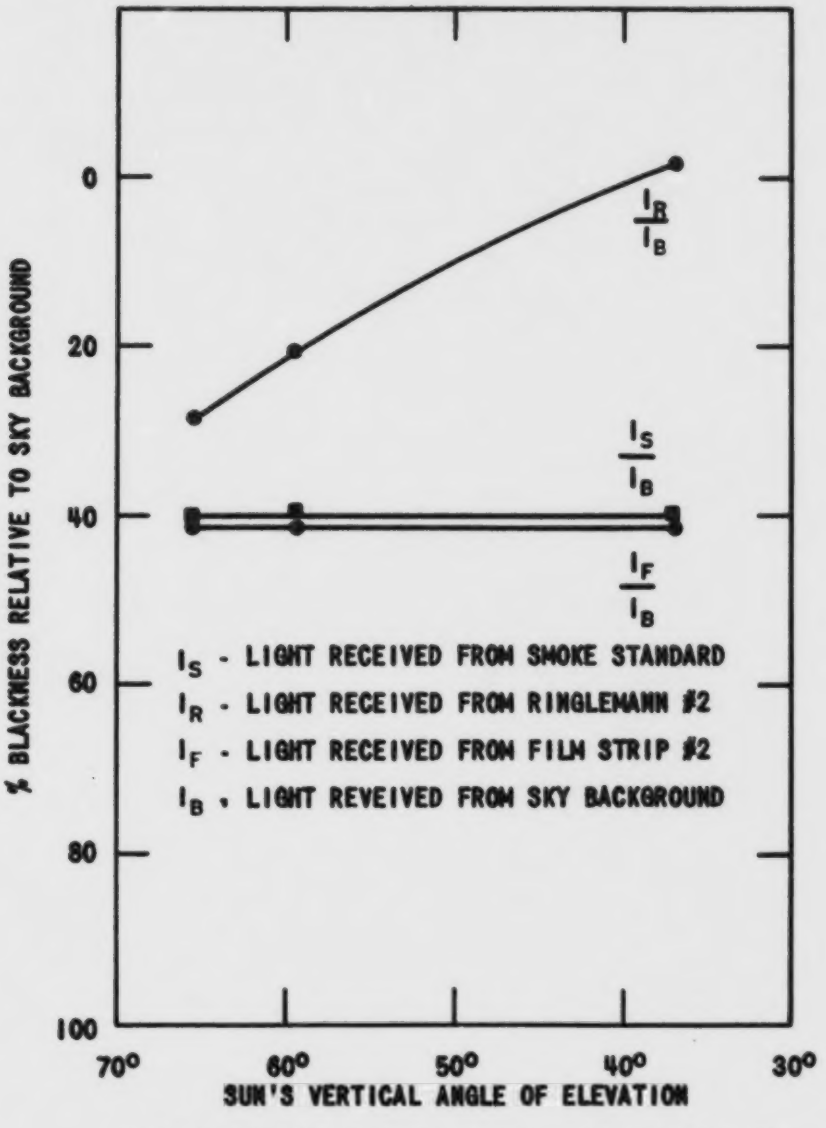


RATIO OF INSPECTION GUIDE TO SMOKE BLACKNESS

CLEAR SUNNY SKY

5/1/57

FIGURE 6



BLACKNESS OF SMOKE, FILM, AND RINGLEMANN
RELATIVE TO SKY BACKGROUND

4/30/57

FIGURE 7

lighting conditions. In this case, however, the Ringelmann Chart shows a decreasing percentage blackness as the sun's position approaches the horizon (angle of incidence of the direct sunlight to the guide surface approaches zero). In the previous case, however, where the guides were oriented with the normal running north and south, the percentage blackness increases as the sun approaches the horizon. This difference in behavior can be explained in terms of the cosine law of illumination, which states the illumination of a surface varies directly as the cosine of the angle of incidence of the direct light to the surface. When only the vertical component of the angle of incidence of the direct sunlight to the guides decreases, the horizontal component being held constant at zero degrees, the illumination increases since the absolute angle of incidence approaches zero. When again considering the first case, in which the chart normal was oriented north and south, the horizontal and vertical components of the angle of incidence of the direct sunlight to the guides were both allowed to vary with the sun's movement. In this case the illumination decreases since the absolute angle of incidence increases as the sun's position approaches the horizon.

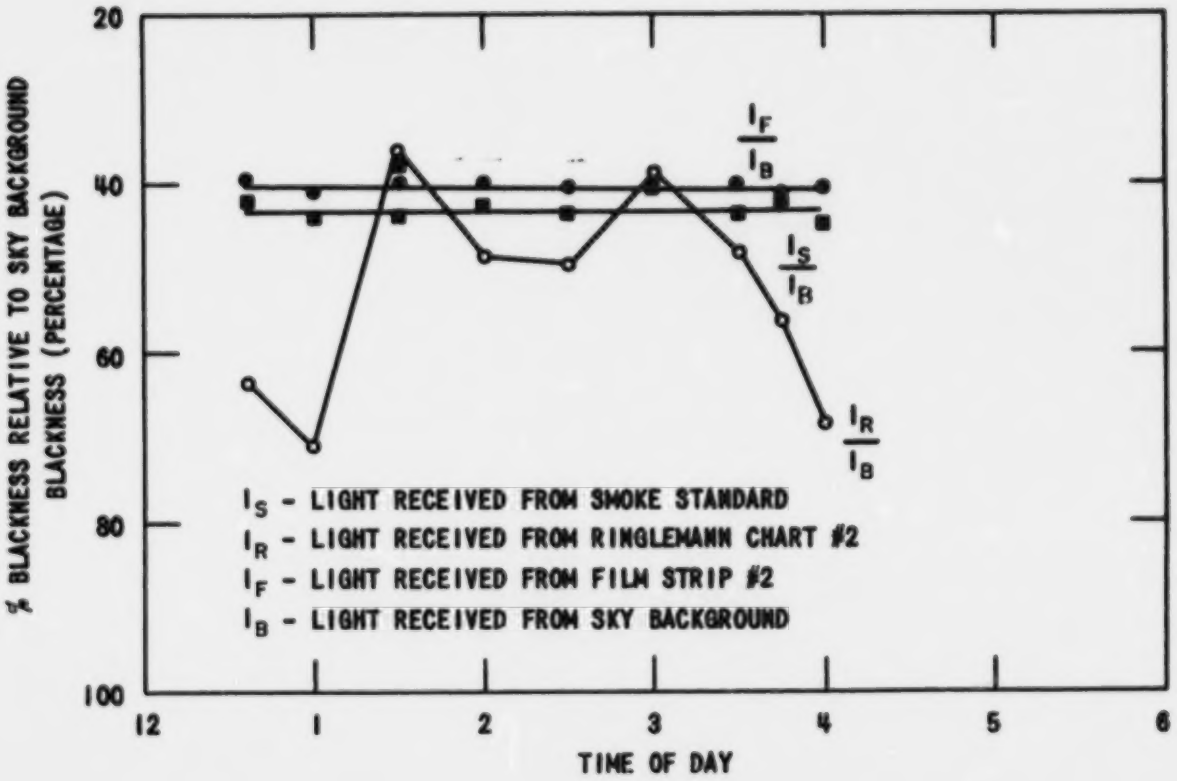
The general effects of the orientation of the guides are observed from these two special cases. First, the orientation of the film or transmittance type guide has no significant effect on the constancy of the results. Second, the orientation of the Ringelmann Chart or reflectance type guide affects the resultant light intensity or degree of

blackness. Fundamentally, the orientation of the reflectance type guide results in varying degrees of blackness, either greater or less than the nominal values specified, depending on the angle of incidence of the direct sunlight to the guide, which is established by the orientation of the guide.

The second phase of the study covers the evaluation made from data obtained during a day of cloudy overcast with occasional breaks in the clouds. This was a period in which the configuration of the cloud cover and, hence, the over-all illumination pattern varied continuously. Readings were not taken, however, during intervals of direct sunlight on the guides. The effects of atmospheric illumination when evaluated on the basis of either a direct or an indirect comparison (Figs. 8,9) show three significant facts: 1) Random variations in atmospheric lighting have no effect on the constancy of percentage blackness of the smoke standard; 2) the degree of blackness of the film strip correlates with that of the smoke standard and is independent of variations in illumination system: 3) the Ringelmann Chart is dependent on the random diffuse background and foreground sky light. Furthermore, under broken cloudy conditions there does not appear to be any trend correlating with the sun's position that would correspond to the trend of effects of direct sunlight observed in the first phase of the study.

GUIDE DEVELOPMENT

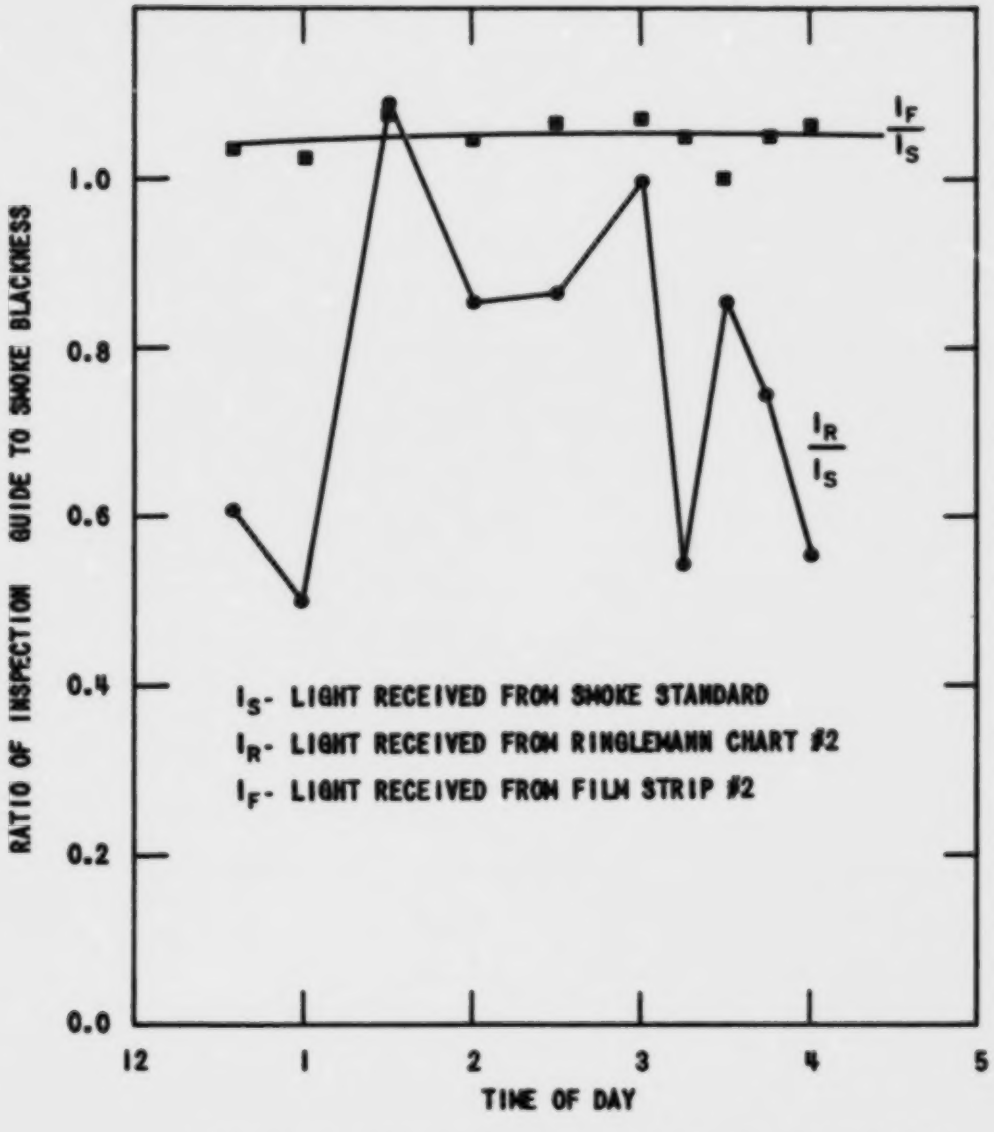
It is realized that all visual comparator type guides have an inherent limitation in that equal optical densities of black smoke plumes do not necessarily reflect equal contaminant discharge to the atmosphere.



BLACKNESS OF SMOKE, FILM, AND RINGLEMANN CHART RELATIVE TO SKY BACKGROUND-BROKEN CLOUDS OVERCAST

5/8/57

FIGURE 8



RATIO OF INSPECTION GUIDE TO SMOKE BLACKNESS
BROKEN CLOUDS OVERCAST

5/8/57

FIGURE 9

The advantages, however, of rapid and simple application offset this limitation and make this method a practical enforcement tool. For these reasons it is felt that the development of a smoke guide which is simple, inexpensive and suitable for general field use, and which correlates with the black smoke plume under field conditions, would be most useful.

A prototype guide was developed utilizing exposed photographic film strips (Fig. 10). The selection of a transmittance type guide was made based on performance results. Percent blackness values were chosen corresponding to the nominal Ringelmann Chart values for two reasons: first, to permit the use of the guide without extensive revision of legislation; second, the nominal Ringelmann values have been shown to occur under specific conditions of atmospheric illumination. Enforcement agencies will be given the opportunity to field test prototype guides as a continuation of this study. Evaluation of various forms of the guide will be made to determine ease of application, stability, and effect of environmental interferences. A final version of a transmittance type guide will be based on these field evaluations.

ACKNOWLEDGMENT

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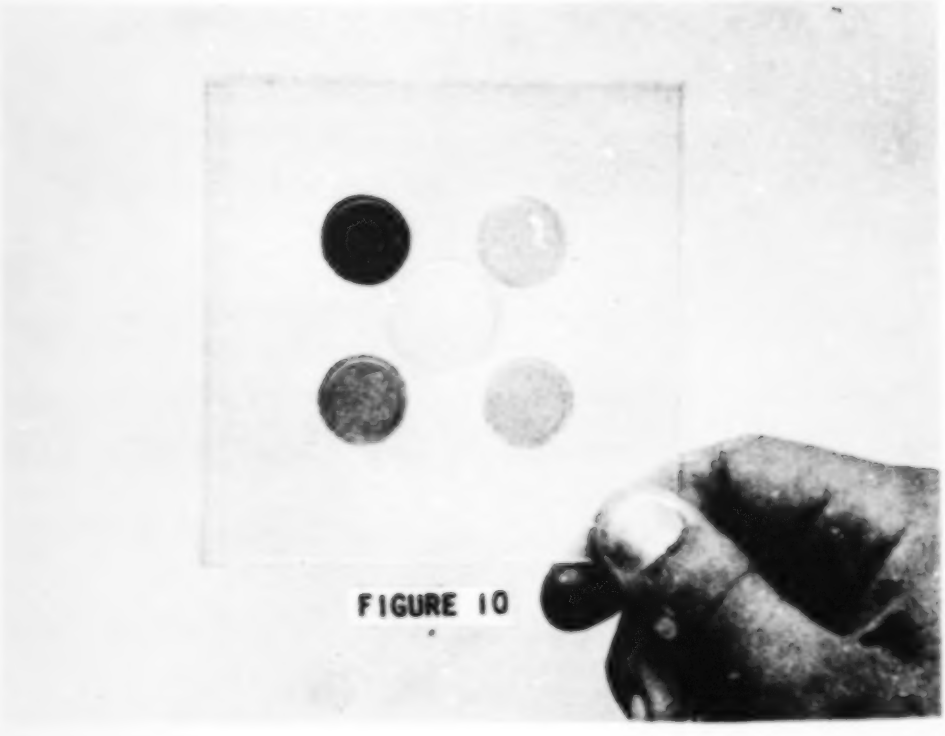

FIGURE 10

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